Report 76-0079

ADDED MASS OF MARINE PROPELLERS IN AXIAL TRANSLATION

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

ADDED MASS OF MARINE PROPELLERS IN AXIAL TRANSLATION

by

James E. Brooks

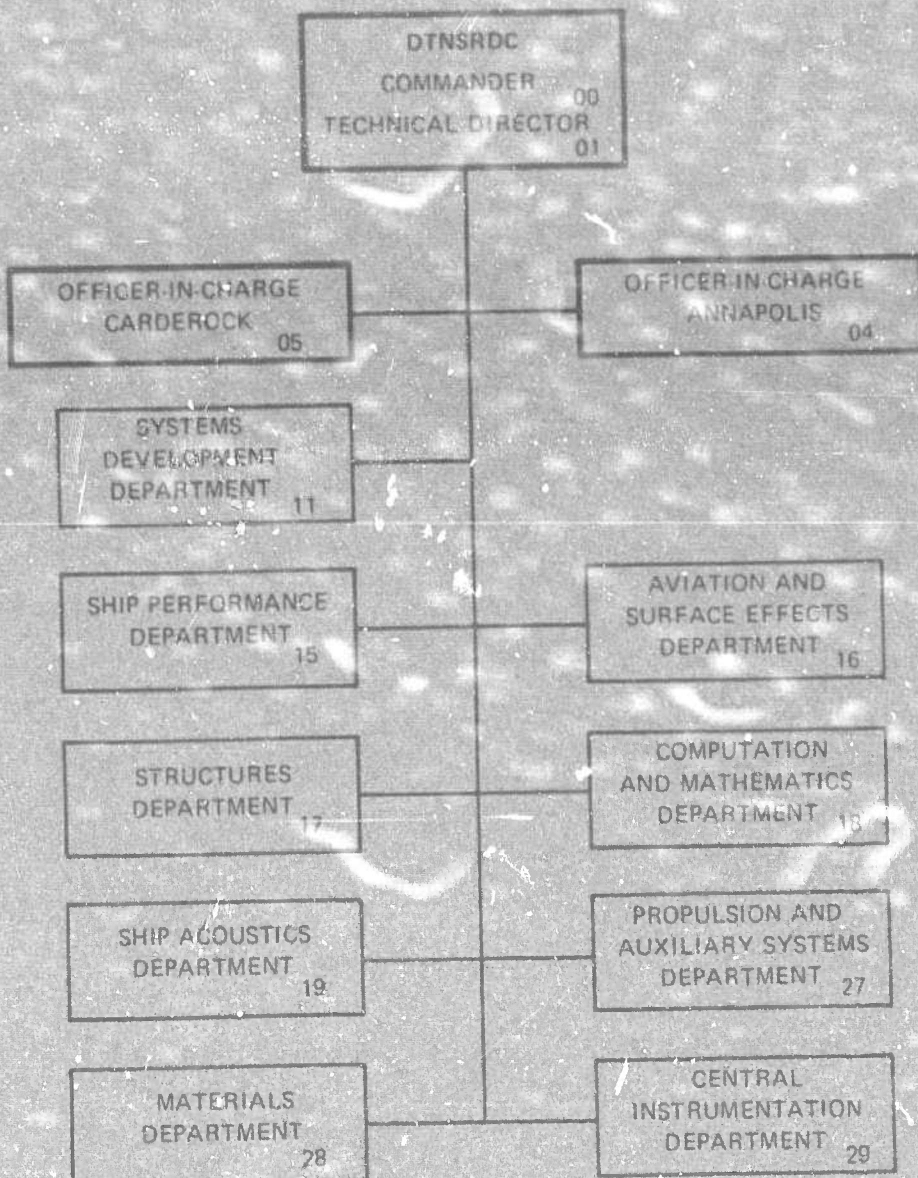
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

SHIP ACOUSTICS DEPARTMENT
RESEARCH AND DEVELOPMENT REPORT

April 1976

Report 76-0079

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

14

1. REPORT NUMBER: DTNSRDC-76-0079

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): 6 ADDED MASS OF MARINE PROPELLERS IN AXIAL TRANSLATION.

5. TYPE OF REPORT & PERIOD COVERED: 9 Final rept.,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): 10 James E./Brooks

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
David W. Taylor Naval Ship Research and Development Center
Bethesda, Maryland 20084

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
61152N, R0001, ZR 011 08 01
1-1903-004

11. CONTROLLING OFFICE NAME AND ADDRESS: 16 ZRØ11-Ø8

12. REPORT DATE: 11 April 1976

13. NUMBER OF PAGES: 12 16 p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 17 ZRØ11-Ø8-Ø1

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Marine Propeller
Added Mass
Propeller Vibration
Propeller Resonance Frequencies in Air and in Water

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Experimental and theoretical values are compared for the added masses of marine propellers and disks in axial translation. The experimental apparatus and procedure are described in detail, but the theoretical model is only outlined. Values predicted by the theoretical model were 15 to 30 percent smaller than the experimental results, except for the case of a circular disk in broadside motion where the results agreed within 2 percent. The generation

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

387682

VB

20. of vorticity on the surfaces of the propellers and disks is proposed as a possible explanation for the discrepancies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Experimental and theoretical values are compared for the added masses of marine propellers and disks in axial translation. The experimental apparatus and procedure are described in detail, but the theoretical model is only outlined. Values predicted by the theoretical model were 15 to 30 percent smaller than the experimental results, except for the case of a circular disk in broadside motion where the results agreed within 2 percent. The generation of vorticity on the surface of the propellers and disks is proposed as a possible explanation for the discrepancies.

ADMINISTRATIVE INFORMATION

This report was prepared as part of the independent research program at the David W. Taylor Naval Ship Research and Development Center under Task Area ZR 011 0801, Work Unit 1-1903-004.

INTRODUCTION

Some years ago, experimental measurements of the added mass of propellers were made by Lewis and Auslander and by Dan, Parsons, and Schloss.[1,2] The present study was conducted to obtain additional experimental values for comparison with one part of a newly developed theory for the flow about a marine propeller operating in the wake of a ship or submarine.[3]

---

[1] Lewis, F.M. and J. Auslander, "Virtual Inertia of Propellers," Journal of Ship Research (Mar 1960).

[2] Dan, A.E. et al., "Measurements of Natural Frequency and Fluid Loading of Propellers Using Mechanical Impedance Instrumentation," NSRDC Report 1955 (Mar 1965).

[3] Chertock, G. and J. Brooks, "A Marine Propeller in a Nonuniform Inflow," DTNSRDC Report (in preparation).

Added mass was determined for two marine propellers and two circular disks which vibrated without rotation in the axial direction. Pure potential flow was approximated by employing very small amplitudes of vibration. The theoretical calculations were based on ideal inviscid potential flow by omitting those parts of the more general theory which account for the production of vorticity and circulation.

EXPERIMENTAL METHOD

The experimental assembly is shown in Figure 1. The model propeller was rigidly supported on an axial rod which was elastically connected to the massive baseplate by two cantilever strips which allowed longitudinal vibration of the propeller and rod but suppressed any rotational or transverse motion.

The lower cantilever was tapered to reduce its drag and added mass. (There is less need to taper the upper cantilever strip since this portion of the assembly is not immersed in water.) The rod had a removable hub assembly to permit easy access to the attached propeller. The irregularities in the hub assembly were minimized by smoothing with molding clay. A threaded bolt at the junction of the rod and the bottom plate provided a means of attaching known additional masses to the assembly without affecting the stiffness. An accelerometer (Endevco Model 2217) was attached to the junction of the rod and the top plate and its output was monitored by a storage oscilloscope (Tektronix Model 5103N).

The characteristic frequency of vibration was determined by setting the system into free vibration and observing the output of the accelerometer on the oscilloscope. This particular oscilloscope is equipped with a memory scope which enables a part of the time history of the motion to be frozen. The characteristic frequency of the system was determined from the sweep speed of the scope and the number of vibration cycles displayed per division. The scope also permits the rate of decay of motion to be measured. In practice, the motion is recorded only for the last stages of vibration when the amplitude of vibration is so small that the motion cannot be perceived by the eye. This minimizes viscous effects and large-amplitude mechanical effects which tend to complicate interpretation of the results.

The procedure was as follows:

1. The resonance frequency was first measured with the system immersed in a barrel of water to a point just below the upper cantilever and with no additional mass attached to the rod.

2. The resonance frequencies were then measured while the system was vibrated in air with different amounts of additional mass fastened to the lower tip of the longitudinal rod.

Auxiliary tests were made to verify that the resonance frequency of the system is unaffected by such variables as depth of propeller submergence, surface waves, boundary effects from sides of the water barrel, and the mounting of the assembly to the barrel.

The "added mass" of the system in water was taken as equal to that mass which must be added to the system in air so that resonance frequencies in the two media match. The "added mass" of the propeller alone was equal to the added mass of the whole system less a small correction (from 2 to 6 percent) for the added mass of the lower cantilever.

The accuracy of the experiment thus depended only on the stability of the sweep speed of the oscilloscope; it was independent of the calibrations of the accelerometer and amplifier and also independent of the mass and elasticity distribution in the mechanical system.

The added masses were measured for NSRDC model propellers: Propeller 4114, a 7.6-in. (19.3-cm)-diameter propeller with five blades and an expanded area of 35.8 in^2 (231 cm^2) and Propeller 4062, an 11.5-in. (29.2-cm)-diameter propeller with seven blades and an expanded area of 63.7 in^2 (411 cm^2). In addition, two tests were made on a 1/16-in. (1.6-mm)-thick aluminum circular disk with a diameter of 6 in. (15.2 cm). In one test the disk was in broadside motion and in the other it was inclined at an angle of 45 degrees.

THEORETICAL METHOD

For the theoretical calculations, the fluid motion induced by the motion of the propeller was assumed to be irrotational and inviscid and to be the same—outside the body of the propeller—as though each propeller blade were replaced by a surface distribution of dipoles along the blade median surface and oriented normal to that surface.

The local dipole density $\mu(\vec{S})$ of this surface layer of dipoles is calculated by solving an integral equation which imposed the condition that at any point $\vec{S}'$ on the outer face of a blade, the normal component of the fluid velocity induced by the dipole distributions over the median surfaces of all the blades must equal the normal component of the vibration velocity at point $\vec{S}'$.

Once the dipole density is determined, the difference in induced velocity potential between two adjacent points $\vec{S}_1$ on the forward face of the blade and $\vec{S}_2$ on the opposite face (and $\vec{S}$ midway between) is expressed as

$$\nu(\vec{S}) = \mu(\vec{S}) - 2h(\vec{S})\ g(\vec{S})$$

where 2h is the blade thickness at $\vec{S}$ and $g(\vec{S})$ is the normal component of the blade velocity $\vec{v}$. Then the total kinetic energy of the water induced by the motion of the propeller is

$$K = B \iint \rho \nu g \ dA(S)$$

where B is the number of blades, and the integration extends over the median surface of one blade. The "added mass" is then defined as

$$M = 2k/v^2$$

The general theory can be applied to any practical propeller with arbitrary pitch, thickness, camber, rake, and skew. The details of the theoretical calculation are given in Reference 3.

RESULTS

Figure 2 shows the resonance frequency versus additional mass curve for Propeller 4114 vibrating in air. This is typical of the experimentally determined curves.

Table 1 summarizes the experimental data; the frequency in air f_{air} is for no additional mass loading and the frequency in water f_{water} is for the propeller immersed in water. The damping is about five times greater in water than in air. The added mass presented in the table is the mass interpolated from a curve such as Figure 2 and includes the added mass due to the motion of the bottom cantilever. It has been determined both experimentally and theoretically that this effect accounts for about 35 grams of the interpolated added mass. A further correction can easily be made to account for damping, but this correction is smaller than the experimental error and is neglected here.

TABLE 1 - SUMMARY OF EXPERIMENTAL DATA

Propeller	f_{air} Hz	Decay in One Cycle percent	f_{water} Hz	Decay in One Cycle percent	Interpolated Added Mass grams
4062	5.78	2	3.98	12	1542
4114	7.74	2.5	5.88	20	608
Disk (broadside)	9.56	3	5.21	15	1240
45 Degree Disk	9.52	3	5.91	15	823

The experimental and theoretical values for the coefficients of added mass for the two propellers and two disks are presented in Table 2. Measurements from previous studies are included for purposes of comparison. The added mass coefficient is equal to the added mass divided by $\rho D^3/3$ which is added mass of a thin disk with the same diameter as the propeller.

TABLE 2 - COMPARISON OF EXPERIMENTAL AND THEORETICAL ADDED MASSES

Propeller	Added Mass/($\rho D^3/3$)			
	Present Study			
	Experimental	Theoretical	Experimental[2]	Empirical[1]
4062	0.180	0.141	0.186	0.188
4114	0.237	0.202	—	0.206
Disk (broadside)	1.02	1.00	1.02	—
45 Degree Disk	0.668	0.500	—	—

The two cases which permit a comparison between the present experimental results and those of Dan et al.[2] showed agreement to within a few percent. The empirical formula of Lewis and Auslander[1] agreed with the experimental value for Propeller 4062 and with the theoretical values for Propeller 4114. However, the present theory agreed with the experimental values only for the case of the disk in broadside motion. The theoretical results were 22 percent smaller than the experimental results for Propeller 4062 and 15 percent smaller for Propeller 4114. There was a similar discrepancy between the present theory and experimental results for three other propellers investigated by Dan et al.[2] but not included here; thus the general trend is for the theory to underpredict experimental values of propeller added mass by from 20 to 30 percent.

The case of a disk inclined at an angle of 45 deg to the direction of motion has a well known potential flow solution which serves as an independent check on the theoretical model. The known solution agreed with the theoretical model but there was no corresponding agreement between theory and experiment. Again the theoretical values were smaller (25 percent) than those determined experimentally.

DISCUSSION AND CONCLUSION

The disagreement between theoretical and experimental results was significant in that the theory consistently predicted values 15 to 30 percent smaller. The one exception was the case of the disk in broadside motion where agreement was very good (within 2 percent).

The theoretical model solves Laplace's equation subject to no normal inflow to the propeller surface. When the theory was checked against known analytical solutions for thick and thin elliptic disks in broadside motion, the agreement was within a fraction of a percent. However, no known independent analytical solution for a propeller or other warped surface is available against which the theory can be compared.

The experiment is simple to conduct and gives repeatable results; they are insensitive to the distribution of elasticity of the system and the actual functional relationship between mass and frequency. Because the amplitude of motion was kept small, viscous effects were presumably minimized. Care was taken to ensure that the frequency of vibration was insensitive to the placement of the system in the barrel of water. The other characteristic frequencies of the system were known to be much higher than the measured vibration and, as such, caused no distortion in the measured results. Overall, the experimental results are judged to be repeatable to within 3 percent.

It is significant that in every experiment except that with the broadside disk, there was a well defined leading edge, trailing edge, and angle of attack Hence it is plausible that except for the one case, vorticity was generated which modified the inertial fluid forces acting on the vibrating mode. However, the magnitude of these forces cannot be predicted at this time.

ACKNOWLEDGMENT

The author is grateful to Dr. George Chertock for suggesting this experiment and for helping with the preparation of this paper.

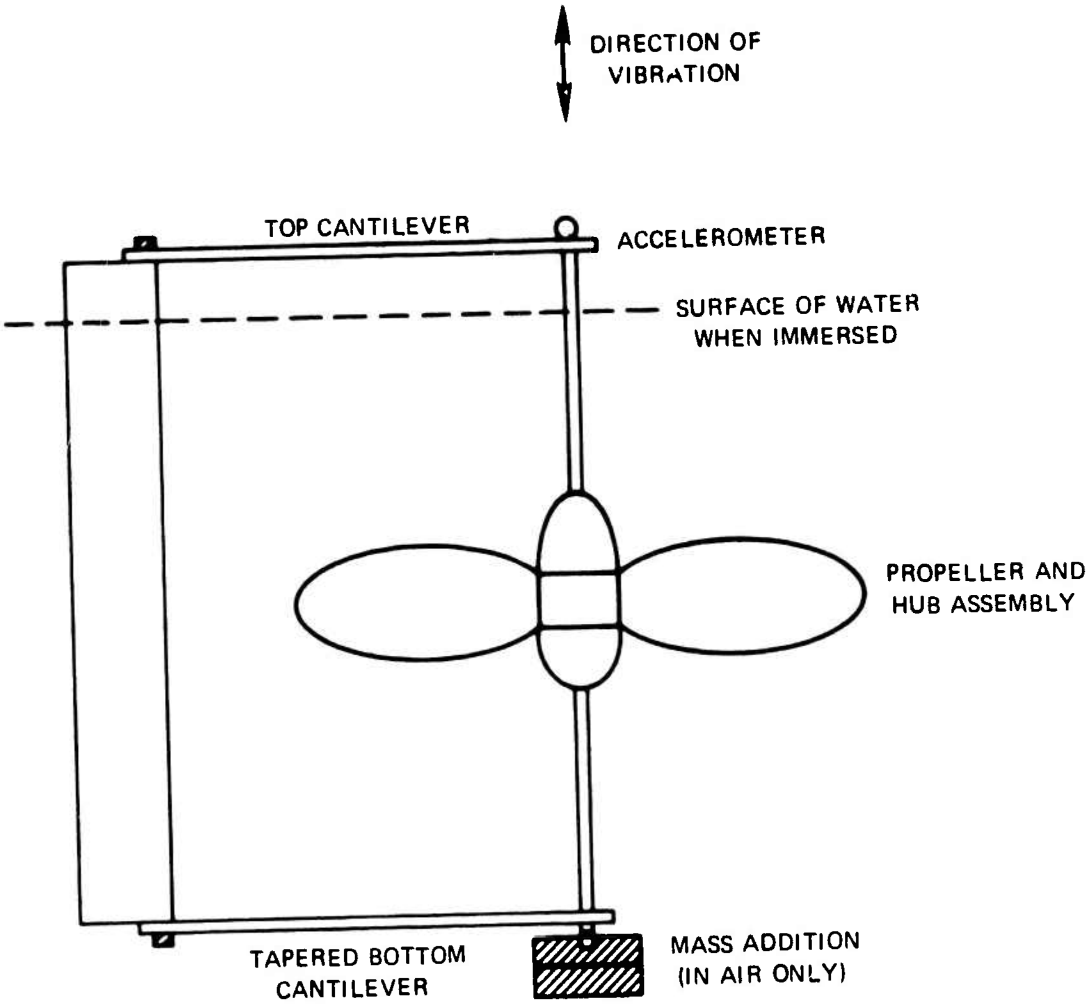


Figure 1 – Experimental Assembly

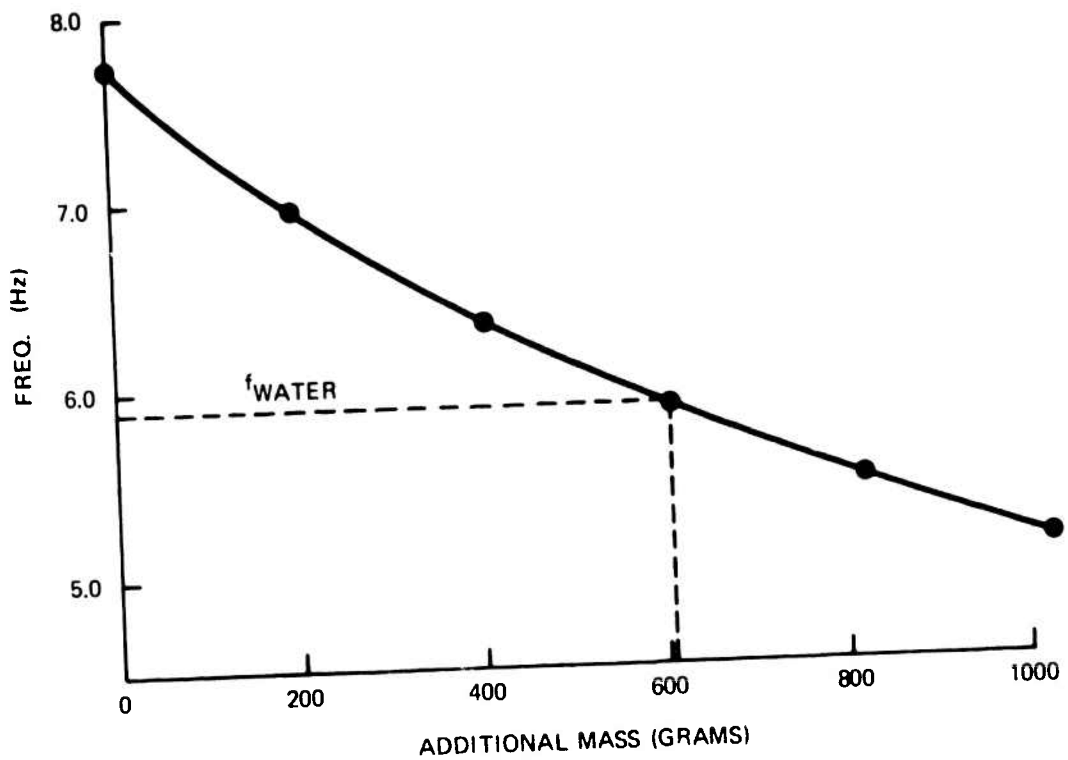


Figure 2 – Resonance Frequency versus Additional Mass for Vibration of Propeller 4114 in Air

INITIAL DISTRIBUTION

COPIES

1 ONR

1 NRL

5 NAVSEA
- 1 SEA 0322
- 1 SEA 033
- 1 SEA 03512
- 1 SEA 037
- 1 SEA 09632

5 NAVSEC
- 1 SEC 6100
- 1 SEC 6110
- 1 SEC 6140
- 1 SEC 6144
- 1 SEC 6148

12 DDC

1 Univ. of Iowa
Inst. of Hydraulic Research
(Dr. L. Landweber)

1 MIT
Dept. of Naval Architecture
(Prof. F.M. Lewis)

1 ARL, Penn State Univ.

1 Stevens Inst. of Technology
Davidson Laboratory

CENTER DISTRIBUTION

COPIES	CODE		COPIES	CODE	
1	012		1	1902	G. Maidanik
1	15		1	1903	G. Chertock
1	1504		1	1940	F. Schloss
1	154	W. Morgan	1	1942	W. Blake
1	1544	M. Miller	1	196	D. Feit
1	1544	R. Boswell	1	1962	A. Zaloumis
1	17		30	5211	Report Distribution
1	1730	J. Ma	1	5221	Library (C)
1	19		1	5222	Library (A)
1	1901	M. Strasberg			

PRECEDING PAGE BLANK-NOT FIL